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Coyote depredation management: current methods and research needs

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Abstract This paper examines the severity of livestock depredation by coyotes (*Canis latrans*), reviews evidence implicating breeding (or "alpha") coyotes in the majority of incidents, evaluates currently used depredation control techniques, and suggests directions for future research. Nonlethal control ranges from varied animal husbandry practices to coyote behavioral modification or sterilization. These methods show significant promise but have not been proven effective in controlled experiments. Therefore, many livestock producers rely on lethal control, and most employ nonselective strategies aimed at local population reduction. Sometimes this approach is effective; other times it is not. This strategy can fail because the alpha coyotes, most likely to kill livestock, are the most resistant to nonselective removal techniques. An alternative is selective lethal control. Livestock Protection Collars (LPCs) and coyote calling are the primary selective lethal approaches. However, LPCs do not have support from the general public due to the toxicant used, and the factors affecting the selectivity of coyote calling have not been studied. The greatest impediments to effective coyote depredation management currently are a scarcity of selective control methods, our lack of understanding of the details of coyote behavioral ecology relative to livestock depredation and wild prey abundance, the absence of solid research examining the effectiveness of different control techniques in a variety of habitats and at multiple predation intensities, and the dearth of rigorous controlled experiments analyzing the operational efficacy of selective removal versus population reduction.

Key words *Canis latrans*, coyote, depredation, livestock, nonlethal control, population reduction, selective control, sheep

Coyotes (*Canis latrans*) are vilified throughout the western United States as insatiable livestock killers. This impression is based on the fact that coyotes are the most important predator of sheep, goats, and cattle. Sheep producers attributed 39,800 sheep and 126,000 lamb deaths (valued at $9.6 million) to coyotes in 1999; this was 61% of losses they ascribed to predators and 22% of their total losses (National Agricultural Statistics Service [NASS] 2000*c*). Coyotes therefore ate their way through 2.3% of the country's 1999 sheep population, which was estimated at 7.2 million individuals (NASS 2000*b*). Coyotes were blamed for the deaths of 21,700 goats in Arizona, New Mexico, and Texas in 1999, out of a total population of 1.3 million. This accounted for 35.6% of the total loss to predators, at an economic cost of $1.6 million (NASS 2000*b*, *c*). Predation was a minor cause of loss to the cattle industry; coyotes killed less than 0.1% of the United States' total cattle population in 2000 (NASS 2000*a*, 2001). In 1995 only 2.7% of total cattle losses were due to predation (and 1.6% of total

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cattle losses were due to coyotes). Respiratory problems, digestive problems, calving problems, and weather each killed 6 to 17 times more cattle than did coyotes (NASS 1996). Nevertheless, coyotes were the dominant cattle predator; they were implicated in 65% of cattle losses due to predation in 2000, or 8,000 cattle and 87,000 calves worth a total of $31.8 million (NASS 2001).

Based on these statistics, coyotes are responsible for over $40 million in damages to livestock producers every year, with proportionally more damage to sheep and goats than to cattle. While this may seem negligible in the face of the $638 million value of the United States sheep industry in 1999 and the $67 billion value of the United States cattle industry in 2000 (NASS 2003), the livestock industry traditionally operates on slim profit margins. For example, a survey with 76 respondents (representing approximately 5% of United States lamb meat production) revealed that net profits per ewe were $3.70 in 1997, –$3.95 in 1998, and –$4.06 in 1999. During this period the annual proportion of ranchers who lost money ranged from 36–64% (United States International Trade Commission 2002). Losses of livestock due to coyote predation can easily transform a narrowly profitable operation into an unprofitable one. The problem is compounded by the fact that coyote damage is not spread equally among producers. High losses at a Montana ranch were documented by O'Gara et al. (1983). These researchers reported 24% and 27% of lambs lost to coyotes during a consecutive 2-year period with minimal coyote control and a 13% loss in the third year despite intensive control. In general, large sheep operations tend to be harder hit by depredation, with 10% of all sheep producers typically losing more than 20% of their lambs to coyotes (Wagner 1988). Producers generally choose to protect their economic interests by controlling their losses, including those related to predation. Because coyote control is so prevalent in ranching areas, it is worth examining the available data concerning coyotes that kill livestock and then evaluating depredation management strategies in light of this information.

Coyote being released for the authors' research investigating conditions that enhance the efficacy of coyote calling.

Not all coyotes kill sheep

Many people believe that every coyote will kill sheep if given the chance. For example, Timm and Connolly (2001) blamed elevated levels of depredation on increased predator abundance at the University of California's Hopland Research and Extension Center (HREC). There is some evidence that supports a relationship between coyote population size and depredation levels, particularly when wild prey is unavailable. Pearson and Caroline (1981) observed that livestock predation rates were highest during periods of low rainfall, when prey populations presumably were at low levels, and O'Gara et al. (1983) noted that predation was highest when sheep arrived on their summer range, which coincided with low rodent populations and coyote pup weaning. A nonsignificant trend between coyote abundance indices and sheep losses was found by Robel et al. (1981).

Stoddart et al. (2001) analyzed 6 years of data during a black-tailed jackrabbit (*Lepus californicus*) irruption and decline at an Idaho site. They concluded that predation rates on ewes and lambs were proportional to coyote density and that coyote population reduction would therefore alleviate sheep losses. However, this relationship was not convincingly demonstrated. For example, total losses were used as a proxy for losses due to coyotes, under the assumption that nonpredation mortality factors were constant during the study. Meanwhile, other lines of evidence strongly indicate that only certain coyotes kill sheep. Connolly et al. (1976) studied the sheep-killing behavior of captive coyotes at HREC and reported that older males and the females with which they were paired were highly likely to attack and kill sheep, while younger males rarely attacked sheep and unpaired females never killed sheep. When mated pairs attacked sheep, the male almost always took the lead. A subsequent series of field studies at HREC (Conner et al. 1998, Sacks et al. 1999*b*, Blejwas et al. 2002) found that breeding (or "alpha") coyotes whose territories overlapped sheep were the primary livestock depredators and that nonbreeders rarely were associated with sheep kills.

Till and Knowlton (1983) found that killing pups of depredating alpha coyotes (denning) reduced sheep kills by 88% in the week following removal and that killing pups and the breeding pair reduced sheep kills by 98%. These researchers suggested that the need to provision pups caused breeding coyotes to maximize foraging efficiency by focusing on large and easily killed prey. They raised the possibility that sterilized coyotes might abstain from killing while maintaining exclusive territories that prevent intrusion by other coyotes. One study has shown a reduction in sheep depredation by sterilized coyotes (Bromley and Gese 2001*b*). This research was conducted in an area where sheep had not been recently grazed, and each pack was exposed to sheep for only 5–23 days per year. While it was promising that the surgically sterilized packs maintained their social structure for the 3-year study (Bromley and Gese 2001*a*), it remains to be seen whether sterilized coyotes will avoid killing sheep that are available for longer periods.

The evidence from HREC suggests that dominant, pair-bonded coyotes eventually will kill sheep if they are available within the coyotes' territory year-round (Blejwas et al. 2002). At HREC, lambing occurred in the winter, before pups were present, yet the dominant coyotes still killed lambs (Sacks et al. 1999*b*). The authors of this study suggested that paired coyotes work cooperatively to attack larger ungulate prey that they would not be able to handle alone. These coyotes may start off with smaller lambs in the winter and then work their way up to adults as they gain experience. Alternatively, the pressures of provisioning pups in the spring may cause alpha coyotes to initially attack older lambs and then adult sheep. Experience with older sheep may then lead to a higher likelihood of coyotes attacking young lambs when they become available the following winter. Observations of coyote attacks on wild ungulates (Gese and Grothe 1995) support the notion that the breeding pair (and particularly the male) takes the lead in successful ungulate attacks and that coyotes do cooperate when making kills. It is reasonable to assume that attacks on other ungulates, such as sheep, goats, and calves, would be conducted in a similar manner.

The available evidence implicates breeders in the vast majority of coyote-caused livestock losses. This evidence does not preclude the possibility of an effect of coyote density on depredation levels because the number of breeders or their behavior relative to sheep may vary with coyote population density and wild prey abundance. For example, regions with high coyote density typically are better coyote habitat, with smaller territory sizes and more breeders per unit area. Increases in depredation levels as wild prey populations decline could be due primarily to an increase in livestock kills by breeders (as opposed to the coyote population as a whole).

Eradicating all coyotes in an area would certainly stop coyote depredations, but this approach may not be cost-effective and has potential ecosystem-level repercussions, such as mesopredator release (Crooks and Soulé 1999) and increased rodent populations (Henke and Bryant 1999). Control methods will be most effective and ecologically sound when they remove the threat posed by breeding coyotes that live where livestock are pastured. The best depredation management techniques would be selective toward specific problem animals, effective at reducing livestock losses for an extended period, have minimal environmental impact, be socially acceptable to the general public, and cost less than the losses they prevent.

Nonlethal depredation management

A number of animal husbandry techniques show promise for meeting these criteria. Fences can be built that, when properly maintained, are nearly 100% effective at preventing coyotes from accessing livestock (deCalesta and Cropsey 1978, Conover 2002). Birthing in sheds, keeping herders with livestock during the day, bedding animals near people for the night, removing or burying carcasses, and lighting corrals where stock are kept at night all have been suggested to reduce depredation (Davenport et al. 1973, Nass 1977, Tigner and Larson 1977, Conover 2002). Guard animals may effectively protect livestock, though not in all circumstances. Guard dogs commonly are used by Europeans and native Americans, and the majority of people who employ dogs to protect sheep and goats report that they reduce predation (Black and Green 1984, Green et al. 1984). Donkeys and llamas, which have a natural dislike for canids, also have been successfully used as guard animals (Conover 2002).

These husbandry techniques are selective, in that they aim to prevent coyotes intent on killing livestock from contacting their prey, and they seem to be effective in certain situations. The public generally approves of these methods because they are nonlethal, selective, and do not cause serious ecological damage. However, some do have ecological impacts; for example, fencing may inhibit wildlife movements (Knowlton et al. 1999), range quality decreases in and around confined bedding grounds (Davenport et al. 1973, Wagner 1988), and guard dogs occasionally will harass wildlife (Black and Green 1984). These husbandry practices also have significant up-front and maintenance costs that must be borne by the producer, ranging from material costs for fencing and sheds to labor costs for herding livestock and training dogs. Guard dogs carry an additional risk, since up to 10% of them eventually harass or kill livestock (Green et al. 1984).

An alternative class of nonlethal depredation management techniques, behavioral modification, has received considerable attention. The aversive-conditioning (or "Clockwork Orange") approach involves using negative reinforcement to train individual coyotes to avoid killing livestock. One experiment with captive coyotes successfully trained 3 of 4 individuals to avoid domestic rabbits (Olsen and Lehner 1978). Another experiment found that coyotes fitted with electronic shock collars could be trained to avoid sheep (Andelt et al. 1999). Both of these studies documented behavioral changes that lasted for over 4 months. However, expenses involved in capturing and conditioning all coyotes in an area that potentially could depredate livestock undoubtedly exceeds the benefits in the majority of situations. Recent research at the National Wildlife Research Center (Shivik and Martin 2000) could make aversive conditioning more cost-effective by using sound-activated shock collars attached to coyotes when they pass through snares; the collar would be activated by special bells attached to livestock. Coyotes that chased animals wearing the bells would be shocked until they left the vicinity.

Another aversive-conditioning approach involves using an emetic (such as lithium chloride) in sheep carcasses and baits to train coyotes to avoid live sheep. There is, however, no evidence that coyotes actually generalize from the baits to live sheep, and producers who tried this technique invariably stopped using it because they felt it was not worthwhile (Conover and Kessler 1994).

Other behavioral modification strategies try to frighten or repel coyotes away from their prey without relying on a conditioning or training phase. Lehner et al. (1976) tested over 45 potential olfactory repellents and did not find any that produced an avoidance reaction. They concluded that olfactory repellents were likely to work only in combination with actual aversive conditioning. Other researchers have used light or sound to scare coyotes. Linhart spent several years developing an "electronic guard" incorporating a strobe light and alarm (Linhart et al. 1984, 1992). He felt these devices were effective for extended periods when multiple guards were used. However, the first experiment was uncontrolled and had several trials (4 of 15) in which predation ceased for less than 4 weeks, and the second experiment was biased in its presentation of loss reductions. Linhart (1992) compared total losses during the entire summer (10–12 weeks) for the year before experimental trials with losses during the latter portion of the summer (<8–10 weeks) that guards were used. This bias would be enhanced if losses decreased through the summer as lambs got larger and breeding coyotes stopped provisioning pups (O'Gara et al. 1983).

Fright tactics like the electronic guard are vulnerable to habituation of coyotes to the stimuli used. The devices may not be effective for more than a few days, and they are usually not recommended for reducing livestock depredation (Koehler et al. 1990, Conover 2002). These techniques might work better if guard device activation was contingent on predator behavior instead of random. When a device fires randomly, coyotes may learn that activation has nothing to do with them. If the device activates only when the coyote approaches a particular pasture or engages in a certain behavior, the coyote is more likely to associate activation of the device with its own actions (Shivik and Martin 2000). Field tests of a Radio Activated Guard (RAG) that was triggered by wolf (*Canis lupus*) radiotransmitters had promising results (Breck et al. 2002), and controlled trials with coyotes showed less habituation to behavior-contingent alarms than to randomly fired alarms (Shivik and Martin 2000). Behavior-contingent frightening stimuli may become an attractive control option, particularly if the prohibitively priced ($3,800 US) RAG could be made affordable by using inexpensive motion or infrared sensors that would detect uncollared predators.

Another nonlethal technique is sterilization of alpha coyotes whose territories overlap sheep. This may reduce depredation when sheep are only seasonally grazed within coyote territories (Bromley and Gese 2001*b*). However, reproductive inhibition will not eliminate killing if ungulate predation results from pair-bonding and cooperative foraging rather than the need to provision pups (Sacks et al. 1999*b*). There currently are no chemical sterilants proven safe and effective for coyotes that will not interfere with territorial behavior, and there is no reliable way to distinguish alphas from betas and transients at the time of capture. Therefore, any reproductive inhibition program would require the capture and physical sterilization of all adult coyotes in an area.

Lethal coyote control: population reduction

Because all of the aforementioned nonlethal coyote control techniques require significant time and initial expense on the part of livestock producers, lethal control is more common. This is particularly true when large numbers of sheep are grazed over an extended area with rough terrain and cover that favors coyotes; nonlethal methods often are impractical under these conditions. Lethal control also is less expensive and less labor-intensive for many producers, since they can supplement their own efforts by calling in predator control specialists who are paid through government sources. However, lethal techniques can vary in their efficacy against problem coyotes and in their tendency to affect nontarget species. Leghold traps, snares, and cyanide ejectors (M-44s) can be used in ways that are highly species-selective, by taking care to use appropriate baits, equipment, and techniques. These methods are not always effective at removing problem coyotes, though. Research at HREC in north-coastal California (Sacks et al. 1999*a*) found that young coyotes were particularly vulnerable to M-44s and that older and alpha coyotes rarely were trapped or snared during the winter lambing season when depredation losses peaked.

Aerial gunning of coyotes is highly species-selective, since shooters verify the target's identity before pulling the trigger. Aerial gunning often is practiced in a population reduction or "preventative" mode, in which coyotes are shot in an area up to 6 months prior to the arrival of sheep. Because preventative aerial gunning is widely touted as an effective management tool, it makes sense to critically evaluate the science upon which this claim is based. The best available research on the efficacy of this method (Wagner and Conover 1999) concluded that gunning significantly reduced lamb losses the following summer. Unfortunately, this study had several problems. Site selection was pseudoreplicated; 6 of the 33 grazing allotments were used 2 or 3 times, which violated the statistical assumption of independent replicates. In addition, the selection of treatment and control plots appeared biased. Wagner and Conover (1999) presented data for 22 of the allotments that tested for differences between treatment and control sites. High variability in losses ensured there were no significant differences in mean losses, yet sites that were later gunned had lower confirmed yearly lamb losses (2.9 versus 5.4), fewer lambs lost to all causes (70 versus 100), and a smaller number of ewes lost to all causes (28 versus 38). The statistical results also were artificially enhanced by a lack of correction for multiple comparisons. Confirmed lamb kills, estimated lamb kills, and lambs lost to all causes were estimated from the same data set, and the alpha level for significance should have been reduced to 0.017. Using the revised alpha level, the only significant result was the finding that gunned allotments had fewer confirmed lamb kills than control allotments. It is unclear whether this result would have been statistically significant if site-selection bias and pseudoreplication were correctly incorporated.

A concurrent study found "no consistent relationship between extent and intensity of aerial hunting and lamb losses or the need for SPM" (Wagner 1997:56), where SPM refers to summer predation management with traps and shooting. Wagner (1997) indicated that the lack of correlation could be explained if gunning effort was biased toward sheep units with more predation, yet there was no correlation between lamb losses for the previous year and the amount or extent of gunning.

Traps, snares, M-44s, and preventative aerial gunning are essentially aimed at reducing coyote population levels; they are nonselective methods used to remove as many coyotes as possible. A study at

HREC found no relationship between subsequent lamb losses and the number of coyotes killed using traps, snares, and M-44s (Conner et al. 1998). Wagner (1988:113) said that the population reduction approach is "something of a sledge-hammer one: If enough coyotes are shot, trapped, and exposed to M-44s… their numbers can be reduced and the chances are that the offending animal(s) will be among those taken and the losses reduced." While this approach likely works to decrease livestock losses in many cases (e.g., Dorrance and Roy [1976] discuss increased losses in the United States after the 1972 toxicant ban), the general public disapproves of techniques that kill large numbers of innocent animals, and this sentiment contributed to California's ban on leghold traps and M-44s in 1998 (California Fish and Game Code 1998). In addition, overuse can decrease the efficacy of these techniques (Sacks et al. 1999*a*), and intensive lethal control affects coyote demographics. Exploited coyote populations have a younger age structure, lower survival, increased juvenile reproduction, larger litters, and smaller packs (Knowlton et al. 1999). If populations are severely reduced, there also is the potential of mesopredator release (Crooks and Soulé 1999), in which small-carnivore populations increase and negatively affect birds and small vertebrates. Henke and Bryant (1999) found that when coyote density was reduced by 50%, rodent and black-tailed jackrabbit density increased, the abundance of badgers (*Taxidea taxus*), bobcats (*Lynx rufus*), and gray foxes (*Urocyon cinereoargenteus*) increased, and rodent species diversity declined.

Lethal selective control

A few lethal control techniques seem to be selective toward depredating coyotes: livestock protection collars (LPCs) and techniques based on coyote calling. Livestock protection collars are the most specific; in one study the devices killed coyotes that attacked sheep in 10 of 14 attacks (Burns et al. 1996). Livestock protection collars are rubber collars that can be placed around the necks of sheep or goats; each collar has 2 pouches filled with poison. When a coyote attacks the throat of an animal wearing a collar, one or both of the pouches usually are punctured and the attacker ingests the toxicant (Conover 2002). Although any poison could conceivably be used in an LPC, the only chemical currently approved by the United States Environmental Protection Agency is Compound 1080, or sodium monofluoroacetate. Compound 1080 is highly toxic to canids; 5 mg will kill a coyote (Burns et al. 1986).

Livestock protection collars filled with Compound 1080 have several drawbacks. The collars are expensive (around $20 US each), the EPA limits the number of collars that can be used in a given area, collars must be closely monitored, and carcasses and spills must be treated as hazardous waste. States are required to have registration, training, and documentation programs before LPCs can be used, and in 1999 only 7 states had these programs in place (Timm and Connolly 2001, Conover 2002). In addition, there are risks of accidental poisoning and secondary toxicity from Compound 1080.

Accidental poisoning occurs when nontarget animals ingest poison that spills out of a ruptured collar. One milliliter of fluid from an LPC exceeds the LD_{50} (the amount of poison that will kill 50% of individuals) of small scavenging birds, golden eagles (*Aquila chrysaetos*), all canids, most mustelids, domestic cats, and bobcats (Wagner 1988). A study examining the potential for nontarget poisoning found that domestic dogs were somewhat susceptible to poisoning, and that scavenging magpies (*Pica hudsonia*) tended not to feed on contaminated material (Burns and Connolly 1995). Because coyotes normally feed on the flank, hindquarters, and viscera rather than the neck (Wade and Bowns 1982), coyotes that scavenge another animal's kill also are unlikely to be poisoned. Innocent coyotes are susceptible to poisoning if they eat regurgitant from a poisoned coyote; in one study the researchers believed that a coyote died in this manner (Burns et al. 1986). Secondary toxicity occurs when Compound 1080 levels are high enough in a poisoned animal to affect other animals that scavenge the carcass. When striped skunks (*Mephitis mephitis*) and golden eagles were fed a diet simulating toxin levels found in coyotes killed by LPCs, all study animals reduced their food intake, and half of the eagles showed sublethal signs of 1080 poisoning (Burns et al. 1991).

The other lethal techniques that show promise for selecting depredating coyotes, denning and calling and shooting, are both based on coyote calling. Calling has been in use for decades (e.g., Alcorn 1946), and involves producing sounds that interest coyotes enough for them to vocally respond or approach. Calling techniques include imitating coyote howls and prey by mouth, making sounds with the help of small reed-based callers, or using sophisticated electronic speakers that store a variety of calls and can be operated by remote control. Denning typically depends on vocal responses to calling; these responses are used by trappers to pinpoint den sites. Once located, the den site is visited and pups or adults are killed; killing only the pups has been shown to temporarily reduce coyote depredations almost as much as killing the entire pack (Till and Knowlton 1983). The combination of calling and shooting is used by itself or in conjunction with denning; coyotes are shot when they approach the site where a call was broadcast. Calling is often used in conjunction with trained dogs that enhance responsiveness to calls and help damage-control specialists find active coyote dens (Coolahan 1990). The selectivity of coyote calling toward breeding males seems to vary depending on the type of call used. Windberg and Knowlton (1990), when they used rabbit distress calls to attract coyotes, found that calling and shooting was biased toward younger animals, but not sex-biased. In contrast, Wagner (1997) found that calling and shooting was strongly sex-biased when pup distress calls, adult coyote calls, and trained dogs were used: 80 percent of coyotes shot were adult males despite an apparently equal population sex-ratio.

Coyote calling has potential as a selective, effective, and inexpensive way of dealing with problem animals. If used sparingly, denning and calling and shooting have minimal population-level or environmental effects; also, the public is more approving of selective control measures than of poisons and indiscriminate trapping and shooting (Reiter et al. 1999). The selectivity of these methods needs to be evaluated experimentally, and their use will remain limited without a more thorough understanding of how coyotes respond to a variety of calls played in different environmental conditions throughout the year.

A variety of common control methods can be used selectively in certain situations. Traps, snares, and M-44s can be set in locations that are more likely to be visited by problem animals (e.g., around sheep bedding grounds or coyote den sites); shooting can be used to kill coyotes as they approach bedded flocks; and aerial gunning can be used in conjunction with coyote calling to remove coyote dens. It is likely these techniques will work well for selective control, but their efficacy remains to be demonstrated.

The future of coyote depredation management research

Past and current research has improved our understanding of coyote ecology and assisted in the development of new and improved control methods, but this is not enough. New studies are needed that will examine coyote behavior and the efficacy of depredation management while following strict experimental protocols under operational conditions. These studies must be well designed, with appropriate controls and randomization. This level of rigor is rare in coyote depredation research, primarily because it is difficult to convince producers to accept a random treatment assignment that could require them to follow a strategy they feel is inappropriate. Much of their resistance probably could be overcome with the establishment of a compensation fund for documented losses that occur when producers participate in research.

We believe that research needs to continue and expand along 4 fronts: studies aimed at developing and improving depredation management techniques; investigations of coyote ecology relative to livestock and natural prey; comparative studies of the efficacy of specific control methods; and examination of the relative costs and benefits of different control strategies in different situations. Specific ideas for research in each of these areas are outlined below. These experiments are not cheap or easy, but they would go a long way toward improving the success and cost-effectiveness of coyote depredation management.

Improved depredation management techniques

This category includes separate phases for technique development and testing. Development should begin with observations of coyote behavior toward control devices and procedures. For example, how do coyotes behave toward guard animals? What do they do after a behavior-contingent guard fires? What are the conditions that increase the responsiveness of dominant individuals to coyote calling? Which coyotes investigate traps set near bedding grounds? Observations and behavioral experiments investigating how marked, free-ranging coyotes behave toward various control methods are crucial for ensuring that techniques are as effective as possible before expensive operational tests are conducted.

Operational testing should incorporate 2 or 3 pairs of sites that are identical with respect to important parameters (e.g., flock size, topography, herding procedures, depredation levels, and previous and ongoing control efforts). One site in each pair should be randomly selected to receive the new control method, and the treatment site should be switched in the following year. Additional sets of sites that differ for some of the important parameters can be included in the experiment or pursued as a separate experiment to determine how the control technique performs across a variety of depredation management conditions. A standardized procedure for using the management technique and measuring its success would be needed to allow for comparisons of efficacy in different situations.

Investigations of coyote ecology

A long-term (≥5 years) experiment is needed that investigates the relationship between coyote population density and depredation levels, examines potential buffering by wild prey, and determines whether depredation results from the actions of a subgroup of the coyote population. This study should be conducted at ≥2 sites, and planned to coincide with natural variation in wild prey abundance (e.g., a black-tailed jackrabbit population irruption and crash, as in Stoddart et al. [2001]). Accurate counts of livestock losses from coyotes would be needed and could be facilitated by using subcutaneous radiotransmitters on a subset of the livestock so that causes of death of missing animals can be estimated. Prey densities can be measured using adequately calibrated line transects (for larger prey like rabbits) and trapping grids for rodents. Coyotes would not need to be captured for this experiment; mark–recapture population estimates can be obtained by analyzing DNA in coyote scats collected along a grid of scat transects. The DNA analysis also would allow for a determination of the social structure, especially if the data were supplemented with DNA from pup scats at den sites. Scat transects also would yield diet information and approximate territory boundaries for coyotes in the population; in addition, the scat DNA can be compared with saliva DNA taken from wounds of dead livestock (Williams et al. 2003) to identify problem coyotes in the population.

Comparative efficacy of control methods

There currently is no solid data on the comparative efficacy of various corrective (i.e., post-depredation) lethal control methods, but this information could be collected with the cooperation of depredation management specialists. Participants would collect predator DNA from saliva samples on dead livestock, then carry out corrective control using methods of their choosing. These methods could include calling and shooting, denning, trapping with snares or leghold traps, use of M-44s, or corrective aerial gunning. As specialists kill coyotes in the area, they would collect a DNA sample from each carcass, note the control method, and record their location. DNA from saliva swabs would be matched to DNA from coyotes removed from the same area to determine whether the livestock killer was taken. This information would be supplemented with geographic habitat and topography data, plus information from livestock producers documenting important covariates (e.g., whether livestock are present year-round, plus their numbers and distribution). Finally, a cost-benefit analysis of the various control techniques could be conducted using additional information concerning the time and physical resources used for control efforts.

Costs and benefits of different control strategies

Several cost-benefit analyses suggest that lethal coyote control is a cost-effective way of solving depredation problems (Nass 1980, Pearson and Caroline 1981, Bodenchuk et al. 2000). These analyses were based on the same group of studies from the 1970s that documented livestock losses in situations with and without lethal control. The studies occurred in a variety of different habitats with multiple types of husbandry practices and differing baseline predation levels. As Pearson and Caroline (1981) noted, comparing these studies was not strictly valid, but it did provide a reasonable starting point for estimating the benefits of predator control.

The accuracy of these and other cost-benefit analyses will be questioned until rigorous controlled experiments produce reliable data about different control strategies. One potential experiment would involve identifying 6 sites that are matched for animal husbandry practices, ecological characteristics, existing coyote control efforts, and livestock losses. At the start of the 3-year study, one-third of the sites would receive no lethal control, another third would receive selective control targeted toward specific problem animals, and the remaining sites would receive coyote population reduction. Control methods would then be rotated for the next year (e.g., of the 2 sites initially receiving no lethal control, 1 would receive population reduction and the other would receive selective control), and the remaining treatment for each site would be applied in the final year. This counterbalanced repeated-measures design should reduce any potential carryover effect, in which the treatment applied in one year affects the results for the following year (Zar 1999). Data collected would include livestock losses and the costs and efficacy of the different control strategies, and the analysis would produce the first accurate assessment of the benefits of lethal control for reducing livestock losses. Replicating this experiment at other groups of sites with different initial conditions would lead to an accumulation of reliable data that livestock producers and control agencies could use to determine the best depredation management strategy for a given situation.

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